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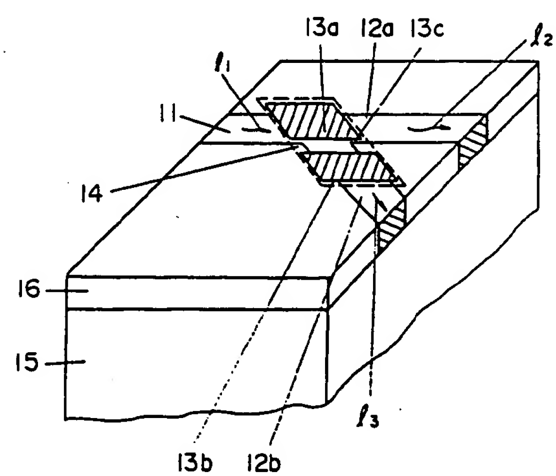
(54) **OPTICAL SWITCH.**

(57) An optical switch for an optical circuit makes use of the electro-optical effect. Electrodes (13a, 13b) are arranged over an optical waveguide (11) which has branch optical waveguides (12a, 12b) and is formed by the employment of an electro-optical material, and a voltage is applied across the electrodes (13a, 13b) to control guided light. The optical waveguides (11, 12a, 12b) to control guided light are formed by a layer of PLZT ((Pb, La)(Zr, Ti)O_3) epitaxially grown on a C-plane of a sapphire (α-alumina) substrate (15).



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SPECIFICATION

OPTICAL SWITCH

FIELD OF THE INVENTION

The present invention relates to an optical switch usable for optical circuits and more particularly to an optical switch of the type including an optical wave guide, branch optical wave guides and electrodes disposed in spaced relation along the optical wave guide, both the optical wave guide and the branch optical wave guides being made of electro-optical material so that transmission of light beams through the optical wave guides may be switched on or off as required.

DESCRIPTION OF THE PRIOR ART

The Mach-Zehder type optical switch has hitherto been known as a typical optical switch. The conventional optical switch of this type is constituted by a Ti-diffused $LiNbO_3$-based optical wave guide. The Ti-diffused $LiNbO_3$-based optical wave guide is divided into two branch optical wave guides in a Y-shaped configuration and light beams transmitted through the one branch optical wave guide are phase modulated under the influence of electro-optical effect. Both the branch optical wave guides are united at another Y-shaped branch at which optical interference takes place whereby switching can be carried out.

However, it is found that the conventional Ti-diffused $LiNbO_3$-based optical wave guide has a refractive index which changes by a small amount under the influence of the electro-optical effect. For instance, the amount of change in refractive index was 0.2×10^{-3} when the electric field required for normal switching operation had a rate of 2 KV/mm. Accordingly, to ensure that switching operation is initiated by a voltage of about 5 V in the presence of phase interference, there is a necessity for designing elements with dimensions larger than 20 mm. For this reason the conventional optical switch cannot be practicably employed when it is to be mounted on an integrated circuit. For instance, when four optical switches are mounted on an integrated circuit, the latter requires a total length of more than 100 mm, inclusive of joint portions between adjacent optical switches where optical wave guides are jointed to one another.

With the foregoing problem in mind, proposals have been made to employ (Pb, La) (Zr, Ti) O_3 (hereinafter referred to simply as PLZT) as an optical switch. Obviously, PLZT is a compound oxide material comprising lead oxide, titanium oxide, zirconium oxide and lanthalum oxide. However, a problem was found with respect to PLZT in that grinding of such a ceramic material to a very small dimension in the order of microns and adhesive connection of ground materials were achieved only with great difficulty. This is because of the fact that the body of an optical switch is required to have a thickness

in the order of microns when an optical switch is used for an integrated optical circuit utilizing excellently high electro-optical effect and the transparency of PLZT.

On the other hand, an optical switch has been proposed in which is used transparent PLZT produced by sintering a plurality of oxide materials comprising lead oxide, titanium oxide, zirconium oxide and tantalum oxide on the base plate made of sapphire. Obviously, it is impossible to grind this transparent material to a thickness in the order of microns as will be seen from the foregoing proposal.

Further, it is well known that material can be easily worked to a very thin thickness by employing a conventional deposition method, for instance, the vacuum deposition method. However, since a required composition cannot generally be obtained when a compound oxide material comprising lead oxide, titanium oxide and lanthanum oxide is processed by employing the conventional deposition method, it is believed that such kinds of compound oxide material cannot be worked to be a thin thickness film on an industrial base by means of presently available techniques.

On the other hand, research works for obtaining a layer of epitaxial PLZT based thin film by employing the sputtering method have been reported. In these research works, a single crystal cubic substrate of MgO and $SrTiO_3$ was used as the substrate material. However, a layer of PLZT based thin film which satisfactorily meets

both the requirements of transparency and excellently high electro-optical effect has not been successfully obtained. It is considered that production of a PLZT based thin film of the above-mentioned type cannot be achieved as long as the presently available techniques alone are utilized.

Furthermore, the Ti-diffused $LiNbO_3$-based optical wave guide suffers from a problem in that the light-transmission loss is increased and the extinction ratio is decreased due to a large extent of mode conversion, unless a single mode consisting of a graded index structure (a structure in which the refractive index is changed in a substantially quadratic manner in the region around the guide) is used. This structure, however, makes it difficult to couple the transmitted light to another optical element and to design an element with very small dimensions. Moreover, it has the drawback that diodes made of semi-conductor in III to V groups for the purpose of detecting transmission of light beams cannot be employed for an integrated circuit. Another drawback is found in that upon producing very small optical components such as microlenses, prisms or the like, heat treatment at an elevated temperature of 1,100°C causes the boundary of a light beam transmission passage to expand due to the occurrence of dispersion and therefore it is difficult to design them with very small dimensions. Accordingly, they cannot be practicably used as optical devices such as base plates for optical integrated circuits.

The inventors have discovered that when a layer of compound oxide material as mentioned above is produced by employing the ion beam deposition method, such as the high frequency sputtering method, a thin film structure having good transparency and excellently strong electro-optical effect can unexpectedly be obtained at high reproduceability by properly selecting the composition of the target for the sputtering process.

The inventors have been able to resolve the foregoing problems inherent to conventional optical switches by using optical wave guides constituted by the above-mentioned PLZT based thin film for producing an optical switch.

SUMMARY OF THE INVENTION

The present invention has been made on the basis of the inventors' dicoveries as mentioned above and its object resides in providing an optical switch constituted by a layer of PLZT based thin film including compound oxide material comprising lead oxide, titanium oxide and lanthalum oxide, the PLZT based thin film structure having good transparency and excellently strong electro-optical properties, which can be made integral with an element for detecting transmission of light beams and is easily designed with very small dimensions and incorporated into an integrated circuit.

To accomplish the above object there is proposed according to the present invention an improved optical

switch of the type including at least an input optical wave guide, two branch optical wave guides, a pair of transmission control electrodes and a branch portion at which the input optical wave guide is branched to the branch optical wave guides the input optical wave guide and the branch optical wave guides being made of electro-optical material and the transmission control electrodes being arranged in spaced relation with a gap having a predetermined width therebetween at a position located on the input optical wave guide or one of the branch optical wave guides, so that transmission of light beams through the input optical wave guide and the branch optical wave guides is controlled by applying a certain voltage to the transmission control electrodes and thereby changing the refractive index of the optical wave guide at the position located below the gap, wherein the improvement consists in that the input optical wave guide and the branch optical wave guides are constituted by a layer of PLZT ((Pb, La) (Zr, Ti) O_3) based thin film which is formed by epitaxial growth on the base plate located on C-plane of sapphire (α-alumina).

According to the present invention, the PLZT based thin film constituting the input optical wave guide and the branch optical wave guides has a mol ratio of Pb/Ti determined to be in the range of $0.65 < Pb/Ti < 0.90$ so that it has good transparency and an excellently strong electro-optical effect. Thus, it is possible to operate the optical switch by application of lower

voltage when switching is to be initiated.

In an embodiment of the invention, the surface of the PLZT based thin layer is constituted with (111)-plane of sapphire so that excellently strong electro-optical effect is assured for the optical switch.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic perspective view of an optical switch in accordance with the first embodiment of the invention.

Fig. 2 illustrates how complex refractive index varies under the working condition of a voltage of 2 KV/mm applied to the optical switch as the mol ratio of Pb/Ti relative to the composition of the thin film layer varies, wherein the variation in the complex refractive index of $LiNbO_3$ is shown by a dotted line for the purpose of comparison.

Fig. 3 illustrates how the complex refractive index of the thin film structure made of high dielectric material varies as the intensity of the electric field varies.

Fig. 4 is a schematic plan view of an optical switch in accordance with the second embodiment of the invention.

Fig. 5 is a fragmental perspective view of an essential part of the optical switch in accordance with the second embodiment, shown on an enlarged scale.

Fig. 6 illustrates how light beam intensity

varies as the voltage applied to the optical switch in accordance with the second embodiment varies.

Fig. 7 is a fragmental perspective view of an essential part of the optical switch modified from the embodiment in Fig. 6, shown on an enlarged scale.

Figs. 8(a) and (b) are fragmental perspective views similar to Fig. 7, illustrating an essential part of the optical switch modified from the foregoing embodiments on an enlarged scale.

Fig. 9 is a schematic perspective view of an optical switch in accordance with another modified embodiment of the invention.

Fig. 10 is a schematic plan view of an optical switch in accordance with another modified embodiment of the invention, and

Fig. 11 is a schematic plan view of an optical switch in accordance with a further modified embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will now be described in greater detail hereunder with reference to the accompanying drawings which schematically illustrate the preferred embodiments thereof.

The present invention consists of an optical switch in which an optical wave guide made of Ti-diffused $LiNbO_3$ is not employed but an optical wave guide made of (Pb, La) (Zr, Ti) O_3 based thin film

(hereinafter referred to as PLZT based thin film) is employed, the last-mentioned optical wave guide being transparent and having an excellent electro-optical effect.

First, description will be made as to an optical switch in accordance with the first embodiment of the invention as schematically illustrated in Fig. 1. The optical switch of the invention as illustrated in the drawing is constructed such that it includes at least an input optical wave guide 11, two branch optical wave guides 12a, 12b, a pair of transmission control electrodes 13a, 13b and a branch portion 14 at which point inputted light beam ℓ_1 is divided into the branch optical wave guides 12a and 12b via the input optical wave guide 11, both the input optical wave guide 11 and the branch optical wave guides 12a and 12b being made of electro-optical material and the pair of transmission control electrodes 13a and 13b being located opposite to one another with a gap 13c having a predetermined width therebetween located on the input optical wave guide 11 through which inputted light beam ℓ_1 is transmitted or on the branch optical wave guides 12a and 12b through which branched light beams ℓ_2 and ℓ_3 are transmitted, so that the refractive index of the optical wave guide located beneath the gap 13c is varied by applying a certain voltage between the transmission control electrodes 13a and 13b so as to control the intensity of light beams transmitted through the input optical wave guide 11 and

the branch optical wave guides 12a and 12b, wherein the input optical wave guide 11 and the branch optical wave guides 12a and 12b are constituted by PLZT based thin film 16 which is prepared by epitaxial growth of sapphire (α-alumina) on its C-plane which constitutes a substrate 15. Particularly, the PLZT based thin film 16 is made of lead oxide, titanium oxide and lanthanum and the mol ratio of Pb/Ti in the thin film structure is determined to be in the range of $0.65 < Pb/Ti < 0.90$. Fig. 2 illustrates measured values representing the electro-optical effect of the thin film, wherein the measured values obtained as the Pb/Ti ratio is changed are plotted on a characteristic curve. Specifically, the curve 21 in Fig. 2 shows how the electro-optical effect of the thin film structure made of lead oxide, titanium oxide and lanthanum oxide varies in dependence on variations in its composition (that is, in dependence on changes in Pb/Ti ratio). For the purpose of comparison, a linear line 22 is shown in the drawing which represents the properties of $LiNbO_3$ single crystal, which is widely used as a material for optical integrated circuits these days. It will be readily apparent from the drawing that PLZT based thin film has an electro-optical effect stronger than that of $LiNbO_3$ single crystal while the Pb/Ti ratio is determined to be in the range of $0.65 < Pb/Ti < 0.90$ and therefore it is practicable employable. However, in the case of $Pb/Ti \leq 0.65$ or $Pb/Ti \geq 0.90$ it can be seen that PLZT based thin film has

the same electro-optical effect as that of $LiNbO_3$ or an electro-optical effect weaker than that of the latter. This means that the PLZT based thin film has no practicability in these ranges. It should be noted here that no excellent electro-optical effect can be expected with respect to conventional ceramics materials in the range of $0.65 < Pb/Ti < 0.90$ and measurement data are not available. With the foregoing background in mind the inventors conducted a variety of research and development works for obtaining an optical switch in the form of a thin film structure in the above-mentioned composition range. As a result they discovered an area where an excellently strong electro-optical effect could be obtained, as illustrated in Fig. 2, which was not expected with conventional ceramics materials. Thus, they have invented an optical switch employing a lower operating voltage on the basis of the above-mentioned discovery. Further, they conducted a number of elaborate experiments with respect to the material of the base plate and the crystal structure of this kind of PLZT based thin film. As a result they confirmed the optimum base plate material and crystal orientation for PLZT based thin film structure. As typical growth planes of the thin film structure (111)-plane, (110)-plane and (100)-plane are to be noted. Previously it has usually been considered that (111)-plane has not necessarily the highest value in terms of electro-optical effect but the inventors confirmed that this (111)-plane exhibited a high electro-optical

effect such as is illustrated in Fig. 2. Further, they discovered that (111)-plane on the thin film structure was easy to grow in spite of the fact that it lacked excellent lattice compatibility with C-plane of sapphire, and they also confirmed that C-plane of sapphire was the optimum plane for the base plate usable for the optical switch of the invention.

Next, the present invention will be described below with respect to concrete examples.

Pulverized lead oxide, titanium oxide and lanthanum oxide were weighed such that their mol ratio became 0.72:0.28:0.93 and they were then mixed well. After the mixture was calcined, a part of the burnt mixture was placed on a dish to serve as a target for sputter vaporization. On the other hand, C-plane of sapphire was employed for the base plate 15 and the temperature of the base plate 15 was selectively determined at 580°C and a distance of 3.5 cm was maintained between the base plate and the target. Further, the mixing ratio of a gas mixture comprising argon and oxygen was determined at 3 : 2 and gas pressure was reduced to 5×10^{-2} Torr. After sputtering had been effected for one hour by operating a magnetron sputtering apparatus, a thin film 16 having a thickness of about 400 microns was obtained.

Crystalization of th thin film structure was examined by X-ray diffraction and electron beam diffraction. As a result it was confirmed that (111)-plane was

a grown single crystal thin film. The composition of the thin film 16 was examined by operating an X-ray micro-analyzer and the result was Pb/Ti = 0.75. The electro-optical effect of the thin film structure was evaluated by measuring the change in birefringence with a certain voltage being applied thereto. When voltage was applied at a rate of 2 KV/mm, change in birefringence amounted to 9×10^{-4} which was a value about four times as high as that of $LiNbO_3$. Fig. 3 illustrates the relationship between voltage and birefringence change found as a result of measurements of the electro-optical effect as mentioned above. Specifically, curve 31 in the drawing shows how birefringence change varies as applied voltage varies. It will be readily apparent from the drawing that it varies in the so-called squared fashion relative to applied voltage.

As described above, the inventors have invented an optical switch which utilizes an excellently high electro-optical effect in an area which was not to be expected with the conventional optical switch being made of ceramics material or thin film. Further, they confirmed that epitaxial growth takes place on the (111)-plane of the thin film structure of a semi-conductor such as Si, GaAs or the like by employing, for instance, the gas phase growing method, particularly on (0001)-plane. Since a thin film made of semi-conductor as mentioned above can be modified to p - n structure or p - i - n structure in accordance with the

conventional semi-conductor processing method to produce an optical detecting element, it is possible to integrate a modulating element with an optical detecting element.

Further, the inventors examined the above-mentioned structures elaborately. As a result they discovered another useful structure and they have invented another useful optical switch on the basis of their discovery. Referring to Fig. 4, the same parts or portions as those constituting the optical switch in Fig. 1 are identified by the same reference numerals. The optical switch as illustrated in Fig. 4 is constructed such that the branch portion 14 is designed in a Y-shaped branch 14a at which inputted light beam transmitted through the input optical wave guide 11 is equally distributed into two parallel extending branch optical wave guides 12a and 12b which are united at another Y-shaped branch 14a to be connected to the output optical wave guide 21, at least the one branch optical wave guide 12a being located between the pair of transmission control electrodes 13a and 13b which serve to reduce the refractive index of the branch optical wave guide 12a with a certain voltage being applied to the transmission control electrodes 13a and 13b so that phase interferrence takes place with light beams transmitted through the branch optical wave guides 12a and 12b to control transmission of light beams to the output optical wave guide 21.

As is apparent from Fig. 5, PLZT based thin film 16 is preferably formed with a ridge portion 51 raised from the

upper surface thereof so that the input and output optical wave guides 11, 21 and the branch optical wave guides 12a, 12b are built by the ridge portion 51.

Further, the inventors discovered that the optical wave guide structure including the PLZT based thin film with the ridge portion formed thereon in that way was different from the conventional optical switch which had a graded index structure in a single mode and that it could be practicably used as an optical modulating element because of less occurrence of mode conversion and less loss during transmission of light beams. Thus, they succeeded in realizing the optical switch of the invention on the basis of their discovery as mentioned above.

Specifically, as illustrated in Figs. 4 and 5, the optical switch of the invention comprises PLZT based thin film which can be normally used as an optical wave guide and of which the film thickness is in the range of 0.1 to 2 microns and therefore it is different from the conventional optical switch which includes a Ti-diffused $LiNbO_3$ based optical wave guide in the graded index structure. They discovered that when a multi-mode optical wave guide was built in such a structure, the width of the optical wave guide was determined in the range of 3 to 30 microns and the film thickness, that is, the step height as measured between the ridge 51 and the upper surface of the thin film, was determined at less than one fourth of the film thickness of PLZT

based thin film as measured at the ridge portion 51, mode conversion took place without any problem and loss of light beams during transmission could be reduced to less than 20 dB/cm (in case of light beams having a wave length of 1.06 micron) so that it could be satisfactorily put in practical use as an element. Thus, they succeeded in realizing the optical switch of the invention on the base of their discovery as mentioned above. Further, they confirmed that light beam modulation was achieved in the optical switch of the invention at a rate higher than 90% without any particular problem from the viewpoint of practicability and moreover the optical switch of the invention was easy to be coupled to other optical components owing to the arrangement made in the multi-mode. It should be noted that when the step height is determined to be more than one fourth of the film thickness of PLZT based thin film as measured at the ridge portion, or when the width of optical wave guide is determined to be less than 3 microns, loss of light beam during transmission exceeds 20 dB/cm (corresponding to a wavelength of 1.06 μm) and when the width of optical wave guide is determined to be more than 30 microns, an element is designed in larger dimensions and a gap between the pair of transmission control electrodes increases, resulting in the fact that a higher operating voltage is required. Accordingly, designing of an optical switch ffected in such a way has no practicability.

Further, the inventors discovered that the optical switch of the invention as constructed in the above-described manner was easily fitted with microlens designed in very small dimensions due to no occurrence of transverse expansion of the optical wave guide under the influence of thermal diffusion.

Since the optical switch as illustrated in Fig. 4 tends to suffer from increased loss of light beam during transmission because the pair of transmission control electrodes 13a and 13b are located very close to the optical wave guide, the former are preferably spaced away from the latter with a buffer layer 52 being arranged therebetween as illustrated in Fig. 5. However, it has hitherto been believed that PLZT based material has an electro-optical effect higher than that of $LiNbO_3$, which is most popularly used at present, but has a high dielectric constant and therefore, since the buffer layer is usually constructed of a material having a lower dielectric constant, electric field fails to be satisfactorily introduced to the optical wave guide and thereby higher voltage weds to be applied to the pair of transmission control electrodes to achieve sufficient modulation. It has been believed that, for instance, when PLZT based thin film having a dielectric constant of 2000 and a film thickness of 0.35 micron is covered with a layer of tantalum oxide having a dielectric constant of 20 and a film thickness of 0.2 micron and a pair of phase control electrodes with

a gap having a width in the range of 5 to 20 microns disposed therebetween are provided, voltage applied to the optical wave guide was only at a rate of 10 to 50%. Unexpectedly, the inventors confirmed that voltage was actually applied to the modulating element of the invention at a rate in the range of 50 to 80% and therefore it could be put into practical use without any problem.

Description will be made below as to a concrete example of the optical switch of the invention.

As illustrated in Fig. 5, C-plane (0001) of sapphire (α-alumina), the surface of which had been ground, was used as a base plate 15 and PLZT based thin film 16 having a thickness of 0.4 micron was formed on C-plane of sapphire constituting the base plate 15 in accordance with the radio frequency magnetron sputtering process. In this example the composition of the target used for the thin film structure was PLZT (28/0/100), the base plate made of sapphire was kept at a temperature of 580°C during sputtering operation and an electric power of 200 W was consumed when carrying out the sputtering process. The PLZT based thin film 16 thus produced had a structure whose (111)-plane was constituted by single crystal and whose refractive index was 2.6 as measured by using He-Ne laser (having a wave length of 0.6328 micron). Next, the surface of PLZT based thin film was coated with photo-resist over the light beam transmission passage having a width of 20 microns and a configuration

as illustrated in Fig. 4 and it was then subjected to etching to a depth, for instance, of 0.065 nm by using ion beam whereby the ridge portion 51 was formed. Since an effective refractive index generally usable for analyzing light beam transmission passage is found higher in the high thickness film area 52 including the ridge portion 51 than the low thickness film area 53, it follows that light beams are confined to the upper film area 52. This means that the upper film area 52 can be used as an optical wave guide. Next, a layer of Ta_2O_5 film was formed on the thin film structure in the area as defined between the transmission control electrodes and the optical wave guide as a buffer layer in accordance with the magnetron sputtering method. The layer of Ta_2O_5 film thus produced was non-crystalline and its refractive index was 2.1 as measured by using He-Ne laser (having a wave length of 0.6328 micron). Next, the transmission control electrodes 13a and 13b were formed of vaporized aluminum. Thus, an optical switch as illustrated in Fig. 4 was obtained.

After the optical switch as constructed in the above-described manner was produced, its modulation of light beam intensity was measured while only one of the optical wave guides, for instance, the branch optical wave guide 12a, was applied with a certain voltage. The results of these measurements are shown in Fig. 6. In the drawing a curve 61 repr sents how light beam intensity varies as voltage varies. As is apparent from

the drawing, voltage at half wave length for light beam intensity was 10 V when a bias voltage of 60 V was applied. This value is about half that of the conventional optical switch including Ti-diffused $LiNbO_3$ based optical wave guides designed to the same dimensions. This means that the optical switch of the invention has excellent properties compared with those of the conventional $LiNbO_3$ based optical switch and it can be designed in dimensions smaller than half those of the conventional optical switch.

Further, the inventors conducted a variety of elaborate experiments with respect to the construction of the optical switch of the invention produced in that way. As a result, they discovered another optical wave guide having the same electro-optical effect as that of optical wave guides of PLZT based thin film structure. Thus, they invented another useful optical switch on the basis of the above mentioned discovery. It was confirmed that the structure illustrated in Fig. 7 assured the same electro-optical effect as that of the foregoing one. It should be noted that in the drawing the same components as those in Fig. 1 are identified by the same reference numerals. Referring to Fig. 7 again, the surface of the PLZT based thin film 16 is fitted with a load layer 71 made of dielectric material. To ensure that light beams are transmitted only through the load type optical wave guide 72 comprising PLZT based thin film 16 located below the load layer 71, the light

refractive index of the insulative base plate 15 and the insulative load layer 71 is determined to be smaller than that of the PLZT based thin film 16. Further, the inventors have discovered the optimum material for the above described structure and fabricated an optical switch having excellent properties on the basis of their discovery. Specifically, they discovered that the optimum structural material which could satisfactorily resolve the problem of crystal compatibility as between the base plate 15 made of sapphire, the PLZT thin film layer 16 and the load layer 71, as well as the problem relative to refractive index, was concerned with the load layer and the insulative base late. Thus, they found that an optical switch having excellent properties could be obtained on the basis of their above mentioned discovery. The inventors discovered that the load layer 71 should be preferably constructed of at least one selected from a group of oxides such as titanium oxide, tantalum oxide, niobium oxide, zirconium oxide, aluminum oxide or the like and a group of nitrides such as silicon nitride or the like. Further, they discovered that when the above-noted material was processed by employing, for instance, the RF-two electrodes type sputtering method, the magnetron sputtering method, the ion beam sputtering method or the like, crystal in the granular form was not unexpectedly produced on a PLZT based single crystal thin film structure with the use of noncrystalline material and

a layer of thin film oriented in C-axis was formed when using crystalline material such as zinc oxide or the like. Further, they discovered that tantalum oxide was especially suitable for use as the load layer. Namely, it was found that a layer of load layer having excellent properties could be produced by using tantalum oxide, for instance, in accordance with the magnetron sputtering method.

More particularly, a layer of tantalum oxide thin film having a thickness of about 0.2 micron was vacuum deposited on PLZT thin film layer 16 by employing the magnetron sputtering method. When vacuum deposition was carried out with the substrate being kept at a temperature lower than 150°C during depositing operation, a layer of transparent non-crystalline tantalum oxide thin film was formed. Next, the tantalum oxide thin film structure thus formed was subjected to etching in accordance with the photo-lithographic method which has been conventionally employed in the field of semiconductor processing to form a pattern predetermined for an optical wave guide. As a result, the optical wave guide employable for the optical swtich of the invention was obtained. Further, by additionally arranging a pair of transmission control electrodes, a required optical switch was produced.

It was confirmed that besides tantalum oxide other oxide materials such as titanium oxide, niobium oxide, zirconium oxide, aluminum oxide or the like and

other nitride materials such as silicon nitride or the like could be used in accordance with the same processing method as that for tantalum oxide so as to vacuum deposit a load layer in the form of non-crystalline film on PLZT based thin film and therefore they were advantageously employable as materials constituting the optical switch of the invention. Further, it was confirmed that when zinc oxide or the like oxide material was processed on PLZT based thin film by employing, for instance, the RF sputtering method, a layer of transparent film oriented in the C-axis was formed and thereby an optical switch was produced by way of the same steps as those for processing tantalum oxide.

In the foregoing example, description has been made as to the case where the load layer 71 is formed in the band-shaped configuration on the PLZT based thin film structure. However, it should not be limited only to a band-shaped configuration on PLZT based thin film structure 16. Alternatively, the load layer 71 may be formed in any other configuration, as long as the effective refractive index of the PLZT based thin film layer 16 is so increased that light beams are confined within the PLZT based thin film layer 16. For instance, a structure as illustrated in Figs. 8(a) and 8(b) is employable. Referring first to Fig. 8(a), a PLZT based thin film layer 16 is formed on the sapphire C-plane substrate and a load layer 81 is then deposited on the PLZT based thin film layer 16 a thickness different

from that of the latter. When the load layer 81 is constituted, for instance, by tantalum oxide the thickness of which is determined to be 0.2 micron in the thicker area 82 and 0.005 micron in the thinner area 83, the effective refractive index of the PLZT based thin film layer becomes higher in the area 84 located below the thickner area 82 of the tantalum oxide layer than that in the area 85 located below the thinner area 83 of the same. Thus, light beams are transmitted through the PLZT based thin film structure while transmission of light beams is confined within the area 84 located below the thicker area of tantalum oxide layer. On the other hand, in cases such as that illustrated in Fig. 8(b), PLZT based thin film 86 having the stepped cross-sectional configuration is formed on the sapphire C-plane substrate 15 and a load layer 88 is then deposited on the PLZT based thin film structure 86 in the area 87 located above the thicker area of the latter. When the load layer 88 made of tantalum oxide having a thickness of 0.2 micron is deposited on the thicker area 87 having a thickness of 0.5 micron of the PLZT based thin film structure 86 the thinner area of which has a thickness of 0.49 micron, the effective refractive index in the thicker area 87 becomes higher than that in the thinner area 89 whereby light beams are transmitted through the PLZT based thin film structure while transmission of light beams is confined within the thicker area 87. Thus, a required optical switch is

obtainable.

Next, Fig. 9 is a schematic perspective view of an optical switch to which the embodiment of the invention as illustrated in Fig. 1 is applied. The same components constituting the optical switch as those in Fig. 1 are identified by the same reference numerals. As is apparent from the drawing, a main optical wave guide 92 includes a first branch optical wave guide 91a which is constituted by an extension from the input optical wave guide 11 and a second branch optical wave guide 91b is jointed to the branch portion 14 at which the input optical wave guide 11 constituting the main optical wave guide 92 is jointed to the first branch optical wave guide 91a so that a second Y-shaped branch 14c is formed while a pair of transmission control electrodes 13a and 13b are arranged on the second Y-shaped branch 14c. Specifically, the transmission control electrodes 13a and 13b are arranged in spaced relation with a certain gap therebetween in such a manner that a linear line L extending across the main optical wave guide 92 at a certain inclination angle relative to the latter is located between both the transmission control electrodes 13a and 13b, wherein the aforesaid inclination angle is so determined that light beam ℓ_1 transmitted through the main optical wave guide 92 is totally reflected at the area extending from an apex 0 through the gap between both the transmission control electrodes 13a and 13b, the apex 0 being located at the top of a triangle built

by the main optical wave guide 92 and the second branch optical wave guide 91b, whereby reflected light beams are introduced into the second branch optical wave guide 91b. Further, the one transmission control electrode 13b and the light beam leakage control electrode 93 are arranged also in spaced relation with a certain gap being located at the boundary area as defined by the main optical wave guide 92 and the second branch optical wave guide 91b. In the illustrated embodiment the one transmission control electrode 13b is used to function as one of the pair of leakage control electrodes for the purpose of saving the space occupied by the optical switch of the invention. Referring to Fig. 9 again, reference numeral 15 designates a substrate located on C-plane of sapphire. A layer of single crystal located on (111)-plane of PLZT which is a material having an excellent electro-optical effect is deposited on the surface of the substrate 15 to a thickness of 0.5 micron in accordance with the sputtering deposition method. After completion of deposition two optical wave guides 92 and 91b are formed to a width in the range of 4 to 50 microns by employing the photo-lithographic technique. Reference numerals 13a, 13b and 93 each designate an electrode formed on the optical wave guides 91b and 92. In the illustrated embodiment the gap between adjacent electrodes 17, 18, 19 and 20 is determined to be in the range of 2 to 6 microns. When the electrodes 13a and 13b are charged to the

same potential and a certain voltage is applied to the electrodes 13b and 93, a layer having reduced refractive index is produced at the area located below the gap extending between the electrodes 13b and 93 whereby light beams transmitted through the main optical wave guide 92 is totally reflected at the layer having reduced refractive index and it is then further linearly transmitted through the main optical wave guide 92 without any occurrence of leakage to the second optical wave guide 91b. Next, both the electrodes 13a and 13b are loaded with the same voltage which is predetermined such as to meet the requirements for total reflection and both the electrodes 13b and 93 are charged to the same potential. This causes a layer having a reduced refractive index to be formed at the area located below the gap extending between the electrodes 13a and 13b and thereby light beams transmitted through the main optical wave guide 92 is totally reflected at the layer having reduced refractive index so that reflected light beams are introduced into the second branch optical wave guide 91b. Thus, by making the necessary combination as between the electrodes 13a, 13b and 93 and selectively applying voltage to them in that way it is assured that light beam inputted into the main optical wave guide 92 can be further linearly transmitted through the main optical wave guide 92 or can be introduced into the second branch optical wave guide 91b after reflection at the layer having a reduced refractive index while an excellent light beam extinction ratio is maintained.

It should be noted that both in the case of light beams being linearly transmitted and when they are totally reflected while a voltage of 50 V is applied to preselected electrodes, the optical switch in accordance with this embodiment has an excellent light beam extinction ratio of higher than 20 dB.

Next, Fig. 10 is a plan view of an optical switch modified from that illustrated in Fig. 9.

An optical switch in accordance with this embodiment of the invention essentially comprises a main optical wave guide 92, a second branch optical wave guide 91b jointed to the main optical wave guide 92, a pair of transmission control electrodes 13a and 13b arranged in spaced relation with a gap 13c having a constant width located therebetween, the gap 13c extending along the bisector of a triangle formed by both the optical wave guides 91b and 92, the apex of the triangle being located at the position of a second Y-shaped branch 14c, and a leakage control electrode 93 adapted to control leakage of light beams transmitted through the main optical wave guide 92 to the second branch optical wave guide 91b via the second Y-shaped branch 14c, the leakage control electrode 93 being arranged in spaced relation from the transmission control electrode 13b with a second gap 101 having a constant width located therebetwen, the second gap 101 extending in parallel with the gap 13c and across the second branch optical wave guide 91b at a position in the proximity of the second Y-shaped branch 14c.

It has hitherto been believed that in the conventional optical switch of the above-mentioned type including a second gap 101 which extends in parallel with the gap 13c, light beams leaked to the second branch optical wave guide 91b via the main optical wave guide 92 is totally reflected at the layer having reduced refractie index located below the second gap 101 owing to electro-optical effect obtainable when the second gap 101 is influenced by the electrical field but leaked light beams fail to be fully returned to the main optical wave guide 92 because of the geometrical arrangement of the conventional optical switch. Thus, it has been considered that the conventional optical switch has an insufficiently improved light beam branch ratio. However, the inventors discovered that light beam ℓ_1 inputted into the main optical wave guide 92 was transmitted further without any occurrence of leakage of light beams to the second branch optical wave guide 91b in the optical switch of the above-mentioned type by making such an arrangement that the gap 13c was not affected by the electrical field, only the second gap 101 being so affected. Thus, they invented another new optical switch on the basis of their discovery as mentioned abofe. Although the principle underlying the operation of the optical switch has not been clarified, it is believed that there is a decrease in the amount of leaked inputted light beam ℓ_1 due to the existence of a layer having reduced refractive index formed at the area located below the second gap 101 whereby light

beams are transmitted further without any occurrence of leakage to the auxiliary passage and at the same time transmission of light beams is confined within the main light beam transmission passage having high refractive index.

As a result of elaborate research on the optical switch of the invention it has been found that the optimum width of optical wave guide is in the range of 4 to 20 microns. When it has a width of less than 4 microns, the gap bewteen adjacent electrodes measures between 2 to 4 microns but it is impossible to realize the affect of the optical switch of the invention. On the other hand, when it has a width of more than 20 microns, it is also impossible to realise the effect of the optical switch of the invention even when the optical switch is constructed with the same structure as in the foregoing embodiment. The optical switch of the invention can be obtained, for instance, by forming optical wave guides with the same structure as in the foregoing embodiment and then forming a pair of transmissoin control electrodes 13a and 13b and a leakage control electrode 93 at the second Y-shaped branch 14c by employing the aluminum vacuum deposition method and the photo-lithographic technique, each of the electrodes 13a, 13b and 93 having a film thickness of 0.1 micron and a gap width of 4 microns. Further, by preparing a layer having a reduced refractive index at the position located below the gap 13c on the main optical wave guide 92 while the electrodes 13a, 13b and

93 are charged to the same potential and a certain voltage is applied to both the electrodes 13b and 93 so as to produce an electrical field at, for instance, a rate of 10 V/micron, it is found that light beam ℓ_1 inputted into the main optical wave guide 92 is linearly transmitted through the latter with no occurrence of leakage to the second branch optical wave guide 91b. In this case a light beam branch ratio of more than 20 dB is obtainable. On the other hand, when the optical switch is operated under such a condition that the electrodes 13b and 93 are charged to the same potential and a certain voltage is applied to both the electrodes 13a and 13b so as to produce an electrical field at a rate of 10 V/micron, inputted light beam ℓ_1 is fully refracted at the layer having a reduced refractive index located below the gap 13c on the main optical wave guide 92 and reflected light beam ℓ_3 is introduced into the second branch optical wave guide 91b. In this case a light beam branch ratio of more than 20 dB is obtainable with the optical switch of the invention.

Next, Fig. 11 is a plan view of an optical switch modified from that illustrated in Fig. 8. The same or similar components to those in Figs. 1 and 9 are identified by the same reference numerals. The optical switch in accordance with this embodiment is constructed such that it includes a second input optical wave guide 111 located on an extension line from the second branch optical wave guide 91b and a third Y-shaped

branch 112 disposed at the branch portion and the width W_1 of the first and second input optical wave guide 11 and 111 and the first and second branch optical wave guide 91a and 91b is dimensioned so as to gradually increase toward the central part of the third Y-shaped branch 112, wherein the outer peripheral line 113 of the first and second input optical wave guides 11 and 111 and the first and second branch optical wave guides 91a and 91b is designed with a hyperbolic configuration.

It has hitherto been believed that the conventional optical switch of the above-mentioned type has not made the inhibition of natural expansion of transmitted light beams in the transverse direction and thus a sufficiently high light beam branch ratio is not obtained. Furhter, it is believed that since the outer peripheral line of the first input optical wave guide 11 through which inputted light beam ℓ_1 is transmitted in jointed to that in the third Y-shaped branch not in the hyperbolic configuration due to the relation between film thickness and width of optical wave guide, a required transmission mode is not maintained and moreover a higher mode which is liable to deteriorate light beam branch ratio tends often to occur. However, the inventors discovered that in the optical swtich of the invention, inputted light beam ℓ_1 was directly introduced into the optical wave guide 12a without any fear of causing leakage of light beams to the optical wave guide 12b when passing through the branch portion. As a result they succeeded in realizing another

new optical switch as disclosed in this embodiment.

Moreover, they conducted a variety of careful experiments with respect to the structure of the optical switch as so constructed and thereafter found that the optimum width of any optical wave guide was in the range of 5 to 30 microns. When an optical wave guide has a width narrower than 5 microns, transmitted light beams are naturally caused to expand widely in the optical wave guide, resulting the fact that an excellently high light beam branch ratio cannot be obtained. On the other hand, when it has a width wider than 30 microns, the branch portion is designed in larger dimensions and therefore the whole optical switch is constructed to a smaller size only with great difficultly. This means that the optical switch of the invention so dimensioned is not suitably employable for an integrated circuit. Furhter, it was found that the optimum intersection angle at the branch portion of optical wave guides was in the range of 1 to 5 degrees. It is considered that when an intersection angle is smaller than 1 degree, leakage of transmitted light beams tends to occur due to natural expansion of the light beams in the optical wave guide. On the other hand, when it is larger than 5 degrees, a light beam branch ratio higher than 20 dB is easily obtained without any necessity for changing or modifying the configuration of the branch portion. Thus, determination of an intersection angle in this way is not acceptable for the optical switch of the invention.

When the optical switch constructed in the above-described manner is fabricated while a dimension L_1 at the intersection portion is determined to be less than 3 mm, a light beam branch ratio higher than 15 dB can be obtained merely by designing the optical wave guides at the intersection portion in a hyperbolic configuration. Thus, according to the invention, the optical switch of the above-mentioned type can be designed and constructed in smaller dimensions with wider dimensional tolerance than that of the conventional optical switch and thereby an element having good properties in respect to light beam branch ratio and light beam extinction ratio can be produced by utilizing the optical switch of the invention.

Although the principle underlying the operation of the optical switch of the invention has not been sufficiently clarified, it will be readily understood from the foregoing results that light beam inputted in the lower mode can be introduced into the intersection portion while it is transmitted through the optical wave guide in multi-mode and thereafter it is converted to light beams for transmission in the lower mode which quasi-statically corresponds to expansion of the optical wave guide since the outer peripheral lines extend in the hyperbolic configuration at the intersection portion. Further, it is considered that light beams are transmitted with little occurrence of leakage due to the fact that the optical wave guide has a width in the range of 10 to 40 microns at the central part of the

intersection portion, causing natural expansion of transmitted light beams to be reduced. Further, it is considered that the reason why an excellently high light beam branch ratio can be obtained consists in that introduced light beams are transmitted to the optical wave guide as its expansion decrases in the quasi-static manner in quite the same way as when light beams are introduced into the central part of the intersection portion. The optical switch illustrated in Fig. 11 can be produced on a PLZT based thin film structure having a thickness of 0.3 micron by employing the photo-lithographic technique which has been conventionally used in the field of semi-conductor processing. Typically, a load type optical wave guide is formed by way of the steps of vacuum depositing a layer of Ta_2O_5 film having a thickness of 0.2 micron on a resist layer by employing the lift method which belongs to the photo-lithographic technique, the resist layer being prepared with the aid of a negative pattern, and the resist layer being removed with acetone. When the so produced optical wave guide is used, light beams are transmitted therethrough while transmission of light beams is confined in the area located below the layer of Ta_2O_5 film. In the embodiment illustrated in Fig. 11, the intersection portion having an intersection angle of θ_1 is designed in such a manner that the optical wave guide having a width W_1 of 4 microns on the lefthand side of the optical switch, as seen in the drawing, is gradually widened toward the intersection

portion which has a width W_2 of 40 microns at the central part and an approximate length L_1 of 2 mm and it is then gradually narrowed toward the righthand side away from the intersection portion while the outer peripheral lines on both sides are smoothly connected to one another in the hyperbolic configuration. It is confirmed that light beams introduced into the optical wave guide 11 has a light beam branch ratio of 16 dB in the optical switch of the invention, as constructed in the above-described manner.

INDUSTRIAL APPLICABILITY

As will be readily apparent from the above description, the optical switch of the invention makes it possible to produce a light beam detecting element in the integrated structure and moreover to produce an optical element in very small dimensions without any particular difficulty. Accordingly, a number of optical devices can be easily assembled in the form of an integrated circuit. It can be concluded that the present invention has provided many industrial advantages which can be fruitfully utilized by associated industries.

While the present invention has been described above with respect to typical embodiments, it should of course be understood that it should not be limited to these only but various changes or modifications may be made in any acceptable manner without departure from the spirit and scope of the invention as defined by the appended claims.

WHAT IS CLAIMED IS:

1. An optical switch of the type including at least an input optical wave guide, two branch optical wave guide, a pair of transmission control electrodes and a branch portion at which said input optical wave guide is branched to said branch optical wave guide, said input optical wave guide and said branch optical wave guide being made of electro-optical material and said transmission control electrodes being arranged in spaced relation with a gap having a predetermined width therebetween at a portion located on the input optical wave guide or one of the branch optical wave guides so that transmission of light beams through the input optical wave guide and the branch optical wave guide is controlled by applying a certain voltage to the transmission control electrodes and thereby changing the refractive index of the optical wave guide at the position located below said gap, characterized in that the input optical wave guide and the branch optical wave guide are constituted by a layer of PLZT ((Pb, La) (Zr, Ti) O_3) based thin film which is formed by epitaxial growth on the base plate located on C-plane of sapphire (α-alumina).

2. An optical switch as defined in claim 1, characterized in that PLZT based thin film constituting the input optical wave guide and the branch optical wave guides has a mol ratio of Pb/Ti which is determined to be in the range of $0.65 < Pb/Ti < 0.90$.

3. An optical switch as defined in claim 2,

characterized in that the surface of the PLZT based thin film is located on (111)-plane of sapphire.

4. An optical switch as defined in claim 1, characterized in that the PLZT based thin film is formed with a ridge portion which is raised from the surface thereof, said ridge portion serving to constitute the input optical wave guide and the branch optical wave guide.

5. An optical switch as defined in claim 1, characterized in that the PLZT based thin film is formed with a load layer on the surface thereof, said load layer being made of dielectric material and serving to constitute the input optical wave guide and the branch optical wave guide passages.

6. An optical switch as defined in claim 5, characterized in that said load layer is constituted by a material selected from a group of dielectric materials comprising titanium oxide, tantalum oxide, niobium oxide, zirconium oxide, zinc oxide, aluminum oxide and silicon nitride.

7. An optical switch of the type including at least an input optical wave guide, two branch optical wave guides, a pair of transmission control electrodes and a branch portion at which said input optical wave guide is branched to said branch optical wave guide, said input optical wave guide and said branch optical wave guides being made of electro-optical material and said transmission control electrodes being arranged in spaced relation with a gap having a predetermined width therebetween at

a position located on the input optical wave guide or one of the branch optical wave guides, so that transmission of light beams through the input optical wave guide and the branch optical wave guide is controlled by applying a certain voltage to the transmission control electrodes and thereby changing the refractive index of the optical wave guide at the position located below said gap, characterized in that the input optical wave guide and the branch optical wave guides are constituted by a layer of PLZT ((Pb, La)(Zr, Ti)O_3) based thin film which is formed by epitaxial growth on the base plate located C-plane of sapphire (α-alumina), that the branch portion is designed in the form of a Y-shaped branch by means of which light beams transmitted through the input optical wave guide is equally distributed into the branch optical wave guide which extend in parallel with one another to be united at another Y-shaped branch located at the outlet ends thereof, an output optical wave guide being jointed to the branch optical wave guides at the last-mentioned Y-shaped branch, and that the transmission control electrodes are located with the one optical wave guide interposed therebetween so that transmission of light beams is controlled by phase interference of transmitted light beams caused by applying a certain voltage to the transmission control electrodes.

8. An optical switch as defined in claim 7, characterized in that the PLZT based thin film constituting the input optical wave guide and the branch optical

wave guide has a mol ratio of Pb/Ti which is determined to be in the range of $0.65 < Pb/Ti < 0.90$.

9. An optical switch as defined in claim 8, characterized in that the surface of the PLZT based thin film is located on (111)-plane of sapphire.

10. An optical switch as defined in claim 7, characterized in that the PLZT based thin film is formed with a ridge portion which is raised from the surface thereof, said ridge portion serving to constitute the input optical wave guide and the branch optical wave guides.

11. An optical switch as defined in claim 7, characterized in that the PLZT based thin film is formed with a load layer on the surface thereof, said load layer being made of dielectric material and serving to constitute the input optical wave guide and the branch optical wave guides.

12. An optical switch as defined in claim 11, characterized in that said load layer is constituted by a material selected from a group of dielectric materials comprising titanium oxide, tantalum oxide, niobium oxide, zirconium oxide, zinc oxide, aluminum oxide and silicon nitride.

13. An optical switch of the type including at least an input optical wave guide, two branch optical wave guide, a pair of transmission control electrodes and a branch portion at which said input optical wave guide is branched to said branch optical wave guides, said input optical wave guide and said branch optical wave

guides being made of electro-optical material and said transmission control electrodes being arranged in spaced relation with a gap having a predetermined width therebetween at a position located on the input optical wave guides or one of the branch optical wave guides, so that transmission of light beams through the input optical wave guide and the branch optical wave guides is controlled by applying a certain voltage to the transmission control electrodes and thereby changing refractive index of the optical wave guide at the position located below said gap, characterized in that the input optical wave guide and the branch optical wave guides are constituted by a layer of PLZT ((Pb, La) (Zr, Ti) O_3) based thin film which is formed by epitaxial growth on the base plate located C-plane of sapphire (α-alumina), that a second Y-shaped branch is formed by jointing a main optical wave guide to a second branch optical wave guide at the position where the input optical wave guide is jointed to a first optical wave guide, said main optical wave guide being constructed by a combination of the input optical wave guide and the first branch optical wave guide which is formed as an extension from the former, and that the transmission control electrodes are located on the second Y-shaped branch so that light beams transmitted through the main light optical wave guide are transmitted forward through the second Y-shaped branch or totally reflected there at to the second branch optical wave guide by applying a certain voltage to the transmission control electrodes,

thereby reducing the refractive index of the second Y-shaped branch at the position located below the gap.

14. An optical switch as defined in claim 13, characterized in that the PLZT based thin film constituting the input optical wave guide and the branch optical wave guides has a mol ratio of Pb/Ti which is determined to be in the range of 0.65 < Pb/Ti < 0.90.

15. An optical switch as defined in claim 13, characterized in that the surface of the PLZT based thin film is located on (111)-plane of sapphire.

16. An optical switch as defined in claim 13, characterized in that a plurality of leakage control electrodes are arranged in spaced relation with a second gap having a predetermined width between it and adjacent ones at the boundary area as defined by the main light optical wave guide and the second branch optical wave guide so that light beams transmitted through the main optical wave guide is transmitted forward further or fully reflected to the second branch optical wave guide by selectively applying a certain voltage to a predetermined combination of the transmission control electrodes and the leakage control electrodes.

17. An optical switch as defined in claim 16, characterized in that the second gap extends in parallel with the first-mentioned gap.

18. An optical switch as defined in claim 16, characterized in that a second input optical wave guides is provided in the form of an extension from the second

branch optical wave guide so as to form a third Y-shaped branch, that the width of the first and second input optical wave guides and the first and second branch optical wave guides is determined to be in an area located in the vicinity of the Y-shaped branch in such a manner as to increase toward the central part of the third Y-shaped branch and that the outer peripheral lines of the first and second input optical wave guides and the first and second branch optical wave guides extend smoothly therebetween while scribing the hyperbolic track.

FIG. 1

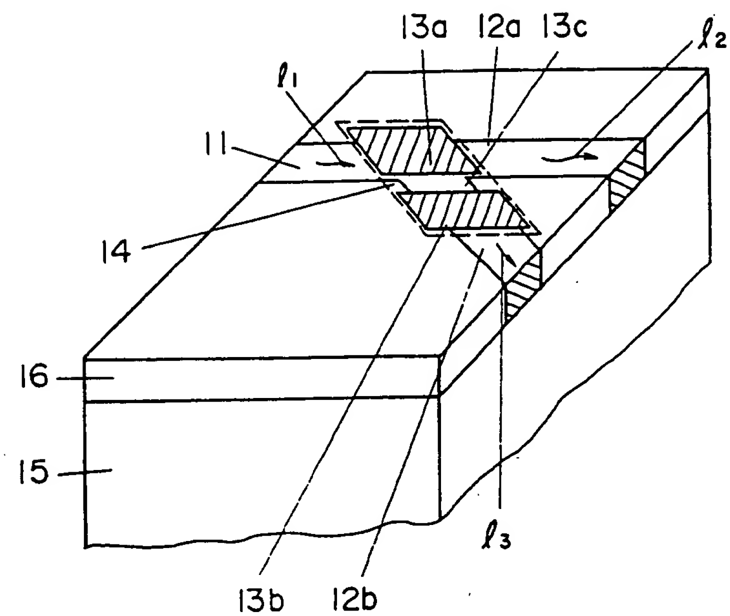


FIG. 2

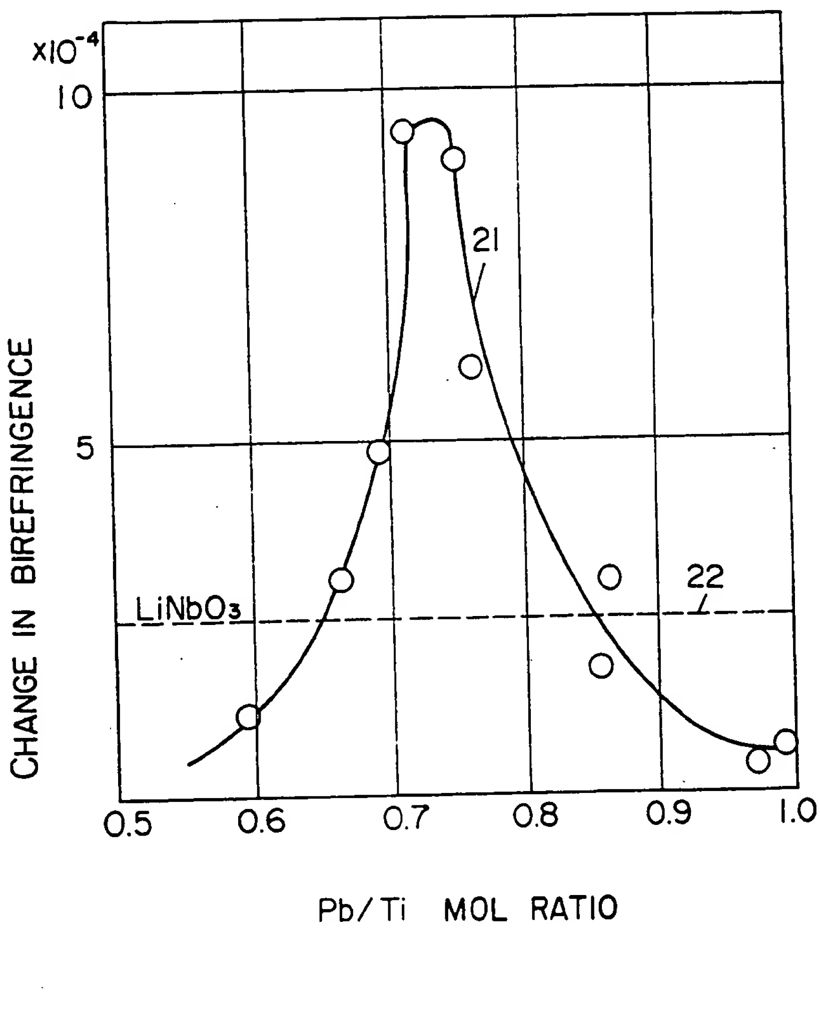

x10^-4
10
5
CHANGE IN BIREFRINGENCE
21
22
LiNbO3
0.5
0.6
0.7
0.8
0.9
1.0
Pb/Ti MOL RATIO

FIG.3

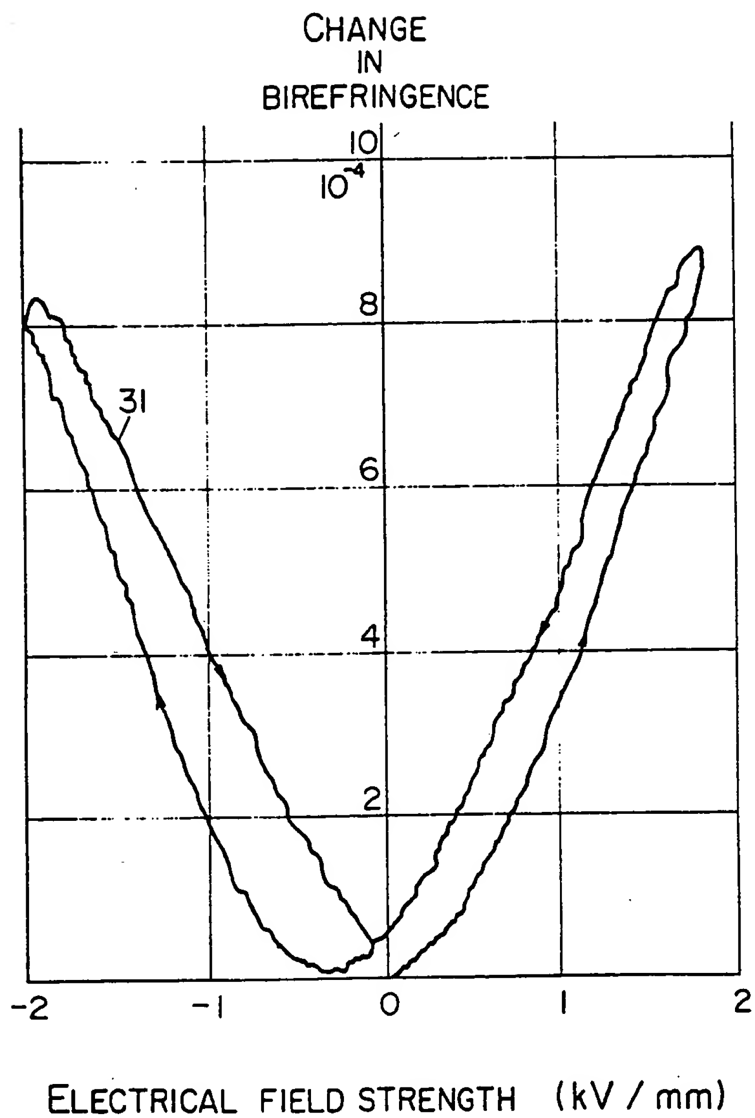

CHANGE
IN
BIREFRINGENCE
10
10^{-4}
8
6
4
2
31
-2
-1
0
1
2
ELECTRICAL FIELD STRENGTH (kV / mm)

FIG. 4

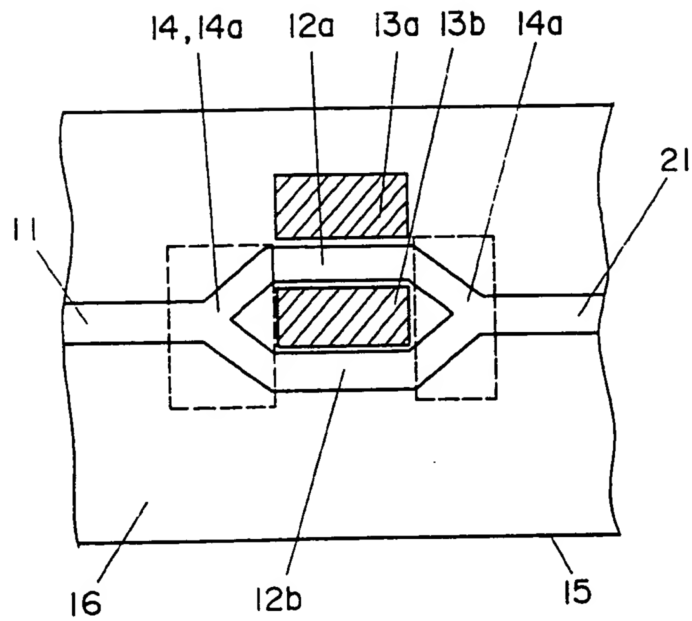


FIG. 5

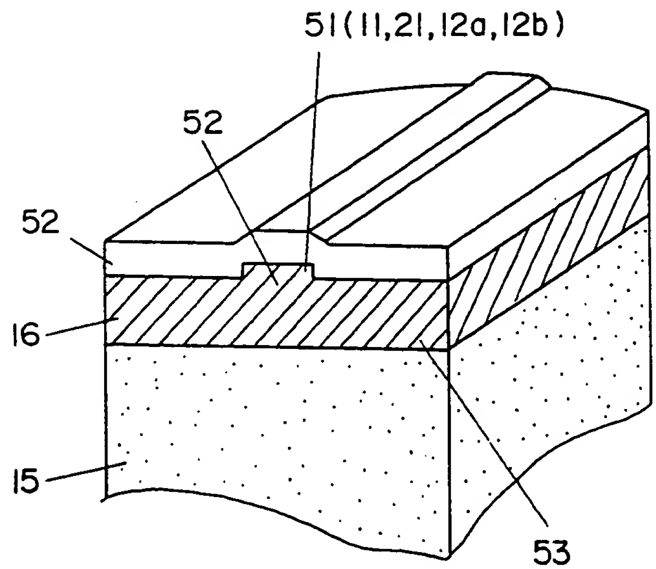


FIG.6

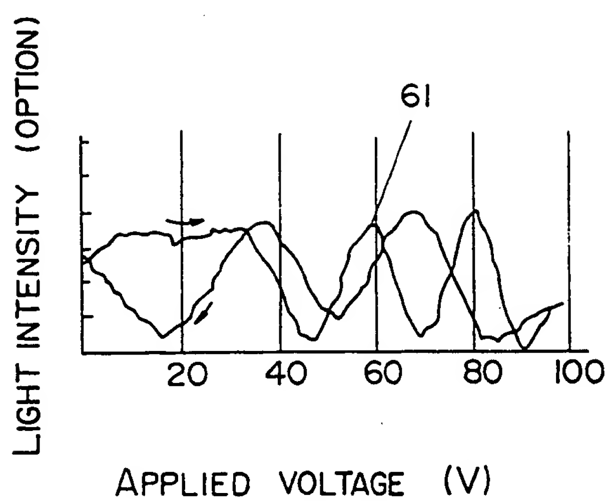


FIG.7

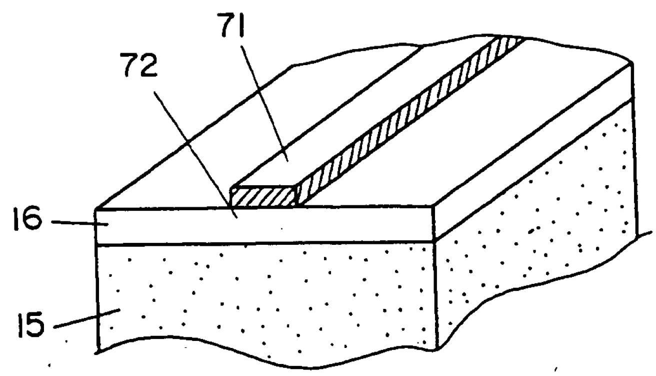
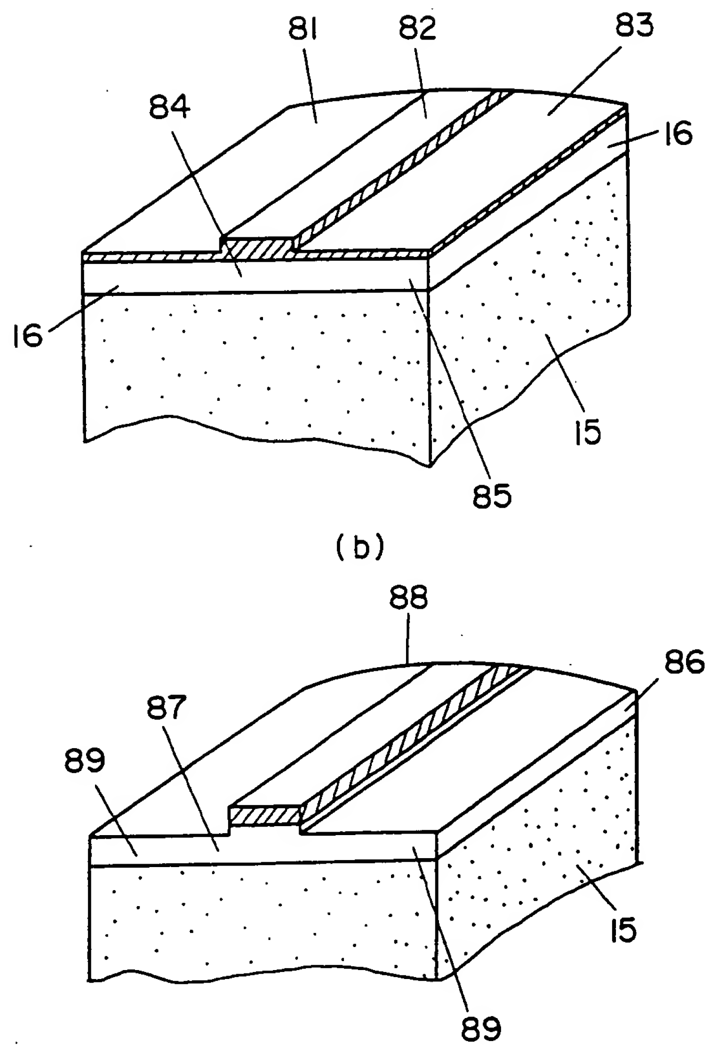


FIG. 8

(a)



(b)

FIG. 9

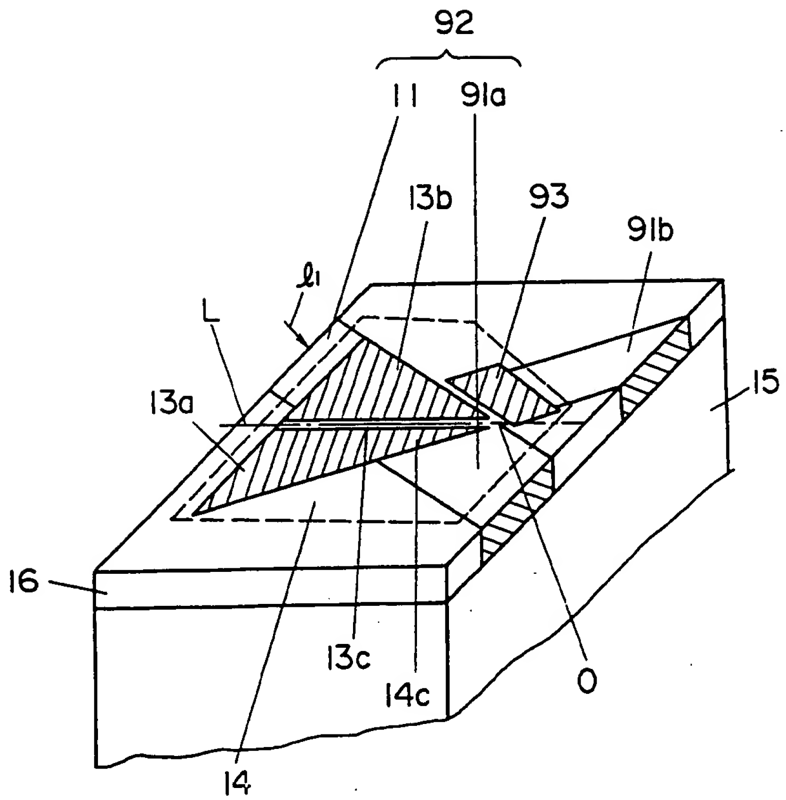


FIG. 10

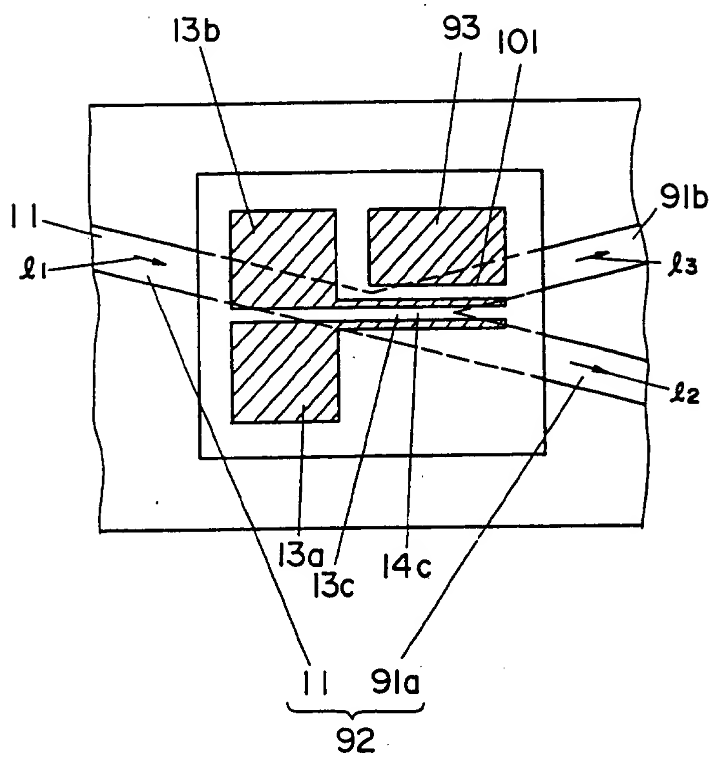
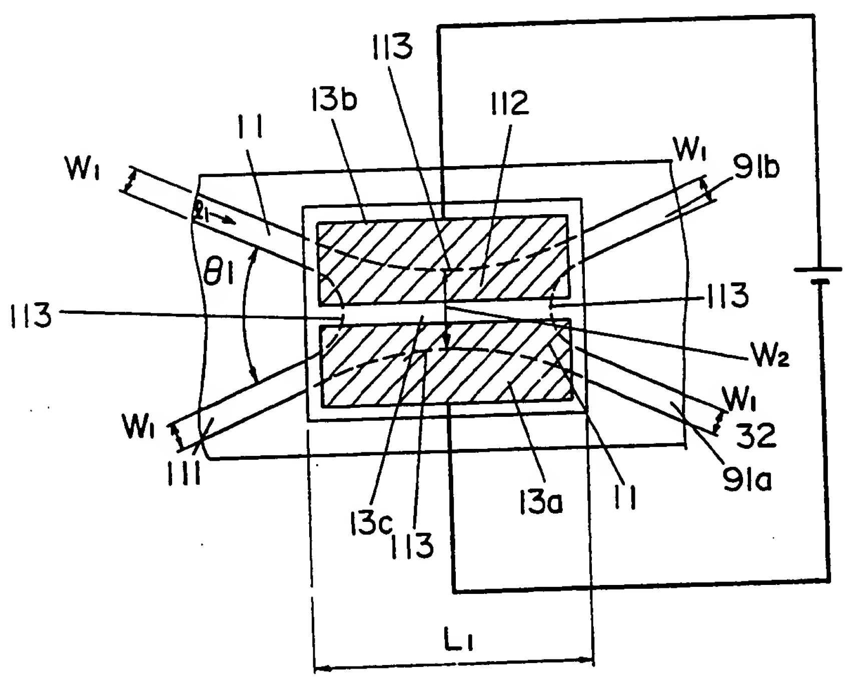


FIG. 11


113
13b
112
11
W1
W1
91b
θ1
113
113
W2
W1
32
W1
111
91a
13c
113
13a
11
L1

LIST OF REFERENCE NUMERAL IN DRAWING

11 ...... Input Optical Wave Guide

12a, 12b ...... Branch Optical Wave Guide

13a, 13b ...... Transmission Control Electrode

13c ...... Gap

14 ...... Branch

15 ...... Sapphire Substrate

16 ...... PLZT Group Thin Film

21 ...... Curve indicating Relationship between Thin Film Composition and Change in Birefringence Index Upon Application of 2 kV/mm

22 ...... Reference Curve indicating Change in Birefringence Index of $LiNbO_3$ upon Application of 2 kV/mm

31 ...... Curve Indicating Relationship between Applied Voltage and Change in Birefringence Index

14a ...... Y-Shape Branch

14c ...... Second Y-Shape Branch

112 ...... Third Y-Shape Branch

22 ...... Output Optical Wave Guide

51 ...... Ridge Portion

61 ...... Curve indicating Relationship between Light Intensity and Applied Voltage with respect to Embodiment

71 ...... Load Layer

72 ...... Load-Type Optical Wave Guide

81 ...... Load Layer

92 ..... Main Optical

93 ...... Leakage Control Electrode

101 ...... Second Gap

113 ...... Outer Peripheral Line

INTERNATIONAL SEARCH REPORT

International Application No. PCT/JP84/00039

0137851

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[3]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl^3 G02F 1/31, G02F 1/05, G02B 5/174

II. FIELDS SEARCHED

Minimum Documentation Searched[4]

Classification System	Classification Symbols
IPC	G02F 1/03, G02F 1/05, G02F 1/07, G02F 1/29 G02F 1/31, G02F 1/315, G02B 5/174

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[5]

Kokai Jitsuyo Shinan Koho	1971 - 1983
Jitsuyo Shinan Koho	1960 - 1983

III. DOCUMENTS CONSIDERED TO BE RELEVANT[14]

Category*	Citation of Document,[16] with indication, where appropriate, of the relevant passages[17]	Relevant to Claim No.[18]
Y	JP, B2, 55-2822 (Hitachi, Ltd.) 22 January 1980 (22. 01. 80) Table 1	2-3, 8-9, 14
Y	JP, A, 58-5718 (Leo Giken Kabushiki Kaisha) 13 January 1983 (13. 01. 83) Fig. 5	7-11
Y	JP, A, 54-7951 (Mitsubishi Electric Corp.) 20 January 1979 (20. 01. 79) Fig. 1	1-6, 13-18
Y	JP, A, 57-97517 (Fujitsu Ltd.) 17 June 1982 (17. 06. 82)	16-18
Y	JP, A, 57-182719 (Matsushita Electric Industrial Co., Ltd.) 10 November 1982 (10. 11. 82)	1-18
Y	Yanai Hisayoshi "Hikari Tsushin Handbook" 1 September 1982 (01. 09. 82) Asakura Shoten (Tokyo) P. 341, P. 262	4-6, 10-12

* Special categories of cited documents:[15]
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search[2]	Date of Mailing of this International Search Report[2]
April 24, 1984 (24. 04. 84)	May 14, 1984 (14. 05. 84)
International Searching Authority[1]	**Signature of Authorized Officer**[20]
Japanese Patent Office	

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

Y	Publication Office The 2nd Meeting on Ferroelectric Materials and Their Applications Hen "Proceedings of the 2nd Meeting on Ferroelectric Materials and Their Applications" (1979) KEIHIN PRINTING (Tokyo) P. 161 - 166	1 - 18
Y	JP, A, 53-96853 (Thomson - CSF) 24 August 1978 (24. 08. 78) Fig. 7 & FR, A, 2379086 & DE, A, 2804105 & US, A, 4196964 & GB, A, 1576595 & FR, B, 2379086	18

V.☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [10]

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1.☐ Claim numbers..........., because they relate to subject matter [12] not required to be searched by this Authority, namely:

2.☐ Claim numbers..........., because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out [13], specifically:

VI.☐ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [11]

This International Searching Authority found multiple inventions in this international application as follows:

1.☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2.☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3.☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

4.☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.